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PREDICTION OF PROCESS PARAMETERS IN TURNING OF TITANIUM ALLOYS USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT

Manufacturing of titanium products is difficult because of its machining. The demand for titanium products is increasing rapidly in the applications of surgical components, nuclear reactors, boilers, human in-plants, automobile industries. Because of the inherent properties like high heat resistant, high strength, high chemical reaction with other metals, machining of titanium alloys is always a challenge for manufacturers by using innovative methodology and machining techniques to improve theproductivity of titanium components. The present study is carried out on three different titanium alloys which are used for machining titanium alloys (Ti-Grade2, Ti-6al-4v, Ti-6al-4vELI) with uncoated carbide tools used. Total experiments are performed under dry environment for reducing the cost and optimizing the parameters of surface roughness and cutting force to predict the value design of expert software, ANOVA used. Machining of titanium alloys with uncoated carbide inserts in a dry environment is not suggestible, machining of grade – 5TI-6AL-4V) with uncoated carbide inserts in a dry environment is good and it will deliver better surface roughness and cutting force compared to other two titanium alloys. Optimal cutting conditions are speed 171.59 m/min, feed 0.12 mm/rev, depth of cut 0.70mm titanium (TI-6AL-4V) grade 5, surface roughness 0.647µm, and cutting force 119.182N.

KEYWORDS: Titanium Alloys, Design of Expert, ANOVA, RSM, Surface Roughness & Cutting Force

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Original Article

INTRODUCTION

Titanium alloys have been generally used in modern manufacturing processes due to the high strengthto-weight ratio at higher temperatures and superior corrosion resistance and thus finds extensive applications in aerospace, automotive, nuclear, chemical, marine and biomedical industries. Titanium alloy with low density, high specific strength, corrosion resistance and good process performance is the ideal structural material, especially for the aerospace engineering and biomedical applications. Titanium alloys have often been classified as difficult-to-machine materials because of low thermal conductivity. The lower modulus of elasticity of titanium leads to considerable spring back after deformation under cutting load, causing titanium parts to move away from cutting tool during machining, which leads to high dimensional inaccuracies in workpieces.

The lower hardness of titanium and higher chemical reactivity leads to a tendency for galling of titanium with a cutting tools and thus changing the tool geometry. The surface roughness of the workpiece is an important parameter, which influences the quality of components. The surface roughness is an estimate of the technological quality of component and also an indicator for evaluating the productivity of machine tools and machined parts. The desired value of surface roughness of a product is generally defined to achieve the required fatigue strength, corrosion resistance, precision fits, tribological and aesthetic requirements. Thus, measuring and characterizing the

surface finish has been considered as the interpreter of machining performance Surface roughness prediction model in terms of cutting speed, feed rate and depth of cut using response surface methodology. It was found that cutting speed and feed rate are the significant machining parameters affecting surface roughness, while the effect of depth of cut is found to be negligible. The use of higher cutting speed with lower feed rate produces a better surface finish, mainly due to high temperature. AzlanMohdZain et al. investigated the effects of the radial rake angle of the tool, combined with cutting speed and feed on surface roughness. They reported that the cutting conditions should be set the minimal surface roughness. Selvakumar et al. Used cermet inserts for finish turning of titanium alloy and observed remarkable effects of tool type and feed rate on surface roughness. Ramesh et al. Conducted experiments on turning of titanium alloy (Grade-5) to study the effects of cutting parameters on surface roughness and found that the feed is the most influential factor affecting the surface roughness. Kali Dials and Chauhan quantified the effects of cutting speed, feed rate, depth of cut and approach angle on surface roughness and tangential force during titanium (Grade-5) alloy machining. The factorial design was utilized to obtain the best cutting conditions for minimization of surface roughness and tangential force.

Ezugwu and Wang2, Ribeiro et al. Rahman et al. Ribeiro et al. performed turning tests on the Ti–6Al–4V with conventional uncoated carbides. They observed certain coherence in the behavior of the titanium alloy in relation to variations in cutting parameters on tool wear and roughness produced in the workpieces. The Poor thermal conductivity of titanium causes the concentration of extreme heat near the cutting edge, which in turn leads to speedy damage of cutting tool. The situation, thus, demands the application of an invention cooling method that would cause successful removal of heat to make implementation of higher cutting speeds viable. Dhar et al. Investigated the role of minimum quantity of lubrication (MQL) on cutting temperature; chip formation and product quality during the turning of AISI-1040 steel with uncoated carbide insert and the experimental results were compared with dry flooded machining. The MQL system has shown encouraging potentials for precision machining at lower fees and high speed (20). The experimental research by Machado and Wallbank indicated that the MQL enables a considerable decrease in cutting temperature and dimensional inaccuracy depending upon the levels of cutting speed and feed rate. The results also showed that surface finish, chip thickness and force variation are all affected with low coolant volume when compared to flood cooling. Vishal et al. Presented MQL, high pressure coolant (HPC), cryogenic cooling, compressed air cooling and use of solid lubricants/coolants techniques in turning, which resulted in the reduction of friction and heat at the cutting zone, consequently leading to an improved productive in the process.

VenkataRamana et al. Evaluated the machining performance and optimized the process parameters in turning off Ti-6Al-4V alloy using an uncoated carbide tool with different coolant conditions for minimal surface roughness. Klocke et al. Reported that the machining efficiency with MQL could be enhanced when compared to dry and conventional flood machining. Ibrahim et al. Optimized the cutting parameters on surface roughness using Taguchi method in Ti-6Al-4V alloy turning with coated and uncoated cemented carbide tools under dry cutting condition and high cutting speed. The conventional tools used for machining of titanium alloys include high speed steel and carbide tools. Due to low thermal conductivity of titanium alloys, these tools can only be used at relatively low cutting speeds. When machining at higher cutting speeds, these tools have a relatively shorter lifetime and hence frequently cutter grinding is necessary. Oosthuizena et al. Found that the performance of conventional tool materials is poor during machining of Ti-6Al-4V at elevated speeds when compared to PCD tools. Response surface methodology used to develop the procedures, which apply statistically designed experiments to obtain the best model with minimum number of experiments and thus reducing the time and cost of experimentation. Hence, an attempt has been made in this paper to find the optimum process parameters, cutting speed,

feed rate, and depth of cut during turning of different titanium alloys using uncoated carbide tools so as to minimize the surface roughness and maximize surface hardness using response surface methodology.

Physical and Mechanical Properties of Titanium Alloys

Table 1

Property	Titanium-GRADE 2	Titanium-GRADE 5	Titanium-GRADE 23
Density(lb/in^3)	0.162	0.159	0.16
Hardness, Rockwell	24	36	35
Tensile strengthMpa)	620	1000	860
Modulus of elasticity(GPA)	100	114	113.8
Melting Range (°C±15°C)	1700	1649	1604-1660
Thermal Conductivity (w/m. K)	8.3	7.2	6.7

EXPERIMENTAL WORK

The work piece materials are titanium alloys (TI-2, TI-6AL-4V, TI-6AL-4VELI) used to machine with uncoated carbide inserts CNMG190612 turning inserts. Design of expert software was used for reducing the experimental trails to cost effective, response surface methodology is used for designing an experimental model. Tool maker's microscope is used for measuring flank wear. The surface roughness was measured by Taylor Hobson surface roughness Tester.

Experimental Plan

Table 2: Process Parameters

Run	Speed m/min	Feed mm/rev	Depth of Cut (mm)	Titanium-	Surface Rough Ness(µm)	Cutting Force (N)
1	100	0.15	0.8	2	0.55	103
2	150	0.15	0.6	2	0.76	129
3	150	0.15	0.8	3	0.63	119
4	100	0.1	0.6	2	0.49	76
5	200	0.15	0.6	1	0.71	153
6	150	0.15	0.4	3	0.85	100
7	150	0.2	0.6	3	0.93	145
8	150	0.15	0.8	1	0.71	141
9	100	0.2	0.6	2	0.61	98
10	150	0.2	0.6	1	0.95	160
11	100	0.15	0.6	1	0.62	118
12	200	0.15	0.6	3	0.71	153
13	150	0.1	0.6	1	0.61	113
14	150	0.1	0.6	3	0.61	96
15	150	0.2	0.8	2	0.87	159
16	200	0.15	0.4	2	0.79	152
17	200	0.15	0.8	2	0.81	172
18	150	0.1	0.8	2	0.67	92
19	200	0.1	0.6	2	0.53	122
20	150	0.2	0.4	2	0.83	168
21	150	0.15	0.6	2	0.76	132
22	200	0.2	0.6	2	0.85	179
23	150	0.1	0.4	2	0.65	97
24	150	0.15	0.6	2	0.74	128
25	100	0.15	0.6	3	0.64	86
26	100	0.15	0.4	2	0.6	82
27	150	0.15	0.6	2	0.75	129
28	150	0.15	0.6	2	0.75	122
29	150	0.15	0.4	1	0.87	123

RESULTS

ANNOVA for Surface Roughness

Table 3

ANOVA for Response Surface Quadratic Model						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**P Value Prob>F**	
Model	0.12	14	8.870E-003	6.60	0.0006	s
A-speed	0.024	1	0.024	18.04	0.0008	
B-feed	0.063	1	0.063	47.05	< 0.0001	
C-depth of cut	3.541E-003	1	3.541E-003	2.64	0.1268	
D-titanium	2.745E-004	1	2.745E-004	0.20	0.6582	
AB	3.188E-003	1	3.188E-003	2.37	0.1458	
AC	4.875E-004	1	4.875E-004	0.36	0.5566	
AD	3.969E-005	1	3.969E-005	0.030	0.8660	
BC	2.202E-005	1	2.202E-005	0.016	0.9000	
BD	2.660E-005	1	2.660E-005	0.020	0.8901	
CD	3.630E-004	1	3.630E-004	0.27	0.6113	
A^2	0.024	1	0.024	17.61	0.0009	
B^2	8.422E-004	1	8.422E-004	0.63	0.4417	
C^2	5.376E-004	1	5.376E-004	0.40	0.5372	
D^2	5.397E-004	1	5.397E-004	0.40	0.5364	
Residual	0.019	14	1.344E-003			
Lack of Fit	0.019	10	1.872E-003	80.29	0.0004	s
Pure Error	9.325E-005	4	2.331E-005			
Cor Total	0.14	28				

The Model F-value of 6.60 implies the model is significant. There is only a 0.06% chance that an F-value this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicates model terms are significant. The "Lack of Fit F-value" of 80.29 implies the Lack of Fit is significant. There is only a0.04% chance that a "Lack of Fit F-value" this large could occur due to noise.

Table 4

Std. Dev.	0.037	R-Squared	0.8684
Mean	0.85	Adj R-Squared	0.7369
C. V. %	4.34	Pred R-Squared	0.2450
PRESS	0.11	Adeq Precision	9.339
-2 Log Likelihood	-130.58	BIC	-80.07
		AICc	-63.66

The "Pred R-Squared" of 0.2450 is not as close to the "Adj R-Squared" of 0.7369 as one might normally expect; i.e. the difference is more than 0.2. All empirical models should be tested by were Confirmation runing."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable.

Final Equation in Terms of Coded Factors

$\sqrt{Ra}$=0.87+0.045A+0.073B-0.017C-0.017C-0.004782D+0.028AB+0.011AC0.00315AD+0.002346BC-0.00257BD-0.00952CD-0.060A^2-0.011B^2+0.009103C^2+0.009122D^2

Final Equation in Terms of Actual Factors

$\sqrt{Ra}$=0.33104+0.00591Speed+1.08757feed+0.46452depthofcut+0.00449titanium+0.011292speed*feed+0.001103

speed*depthofcut0.00006299speed*titanium+0.23463feed*depthofcut0.051572feed*titanium-0.047633depthcut*titanium-0.000241speed^2-4.55780feed^2+0.22759depthof cut ^{2}+0.00912titanium ^{2}

ANNOVA for Cutting Force

Table 5

ANOVA for Response Surface Linear Model						
Source	**Sum of Squares**	**Df**	**Mean Square**	**F Value**	**P- Value prob> F**	
Model	42.11	4	10.53	57.54	< 0.0001	s
A-speed	23.10	1	23.10	126.27	< 0.0001	
B-feed	16.12	1	16.12	88.12	< 0.0001	
C-depth of cut	0.73	1	0.73	4.00	0.0570	
D-titanium	2.15	1	2.15	11.78	0.0022	
Residual	4.39	24	0.18			
Lack of Fit	4.28	20	0.21	8.03	0.0281	s
Pure Error	0.11	4	0.027			
Cor Total	46.50	28				

The Model F-value of 57.54 implies the model is significant. There is only 0.01% chance that an F-value this large could occur due to noise. Values of "Prob> F" less than 0.0500 indicates model terms are significant. If there are many model reduction may improve the model. The "Lack of Fit F-value" of 8.03 implies the Lack of Fit is significant. There is only a2.81% chance that a "Lack of Fit F-value" this large could occur due to noise.

Table 6

Std. Dev.	0.43	R-Squared	0.9056
Mean	11.14	Adj R-Squared	0.8898
C. V. %	3.84	Pried R-Squared	0.8547
PRESS	6.76	Adeq Precision	28.677
-2 Log Likelihood	27.55	BIC	44.39
		AICc	40.16

The "Pred R-Squared" of 0.8547 is in reasonable agreement with the "Adj R-Squared" of 0.8898; I. The difference is less than 0.2."Adeq Precision" measures the signal to noise ratio. A ratio greater than 4 is desirable.

Final Equation in Terms of Coded Factors

$\sqrt{Fc}$=11.14+1.39A+1.16B+0.25C-0.42D

Final Equation in Terms of Actual Factors

$\sqrt{Fc}$=3.60994+0.02248Speed+23.18084feed+1.23455depth of cut -0.42375titanium.

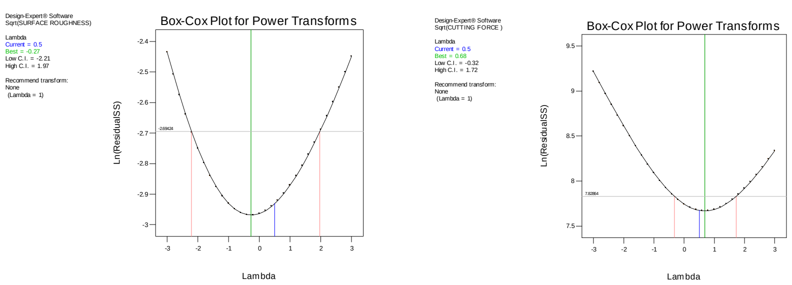

Figure 1: Plot for Box-Cox Power Transforms Ra & Fc

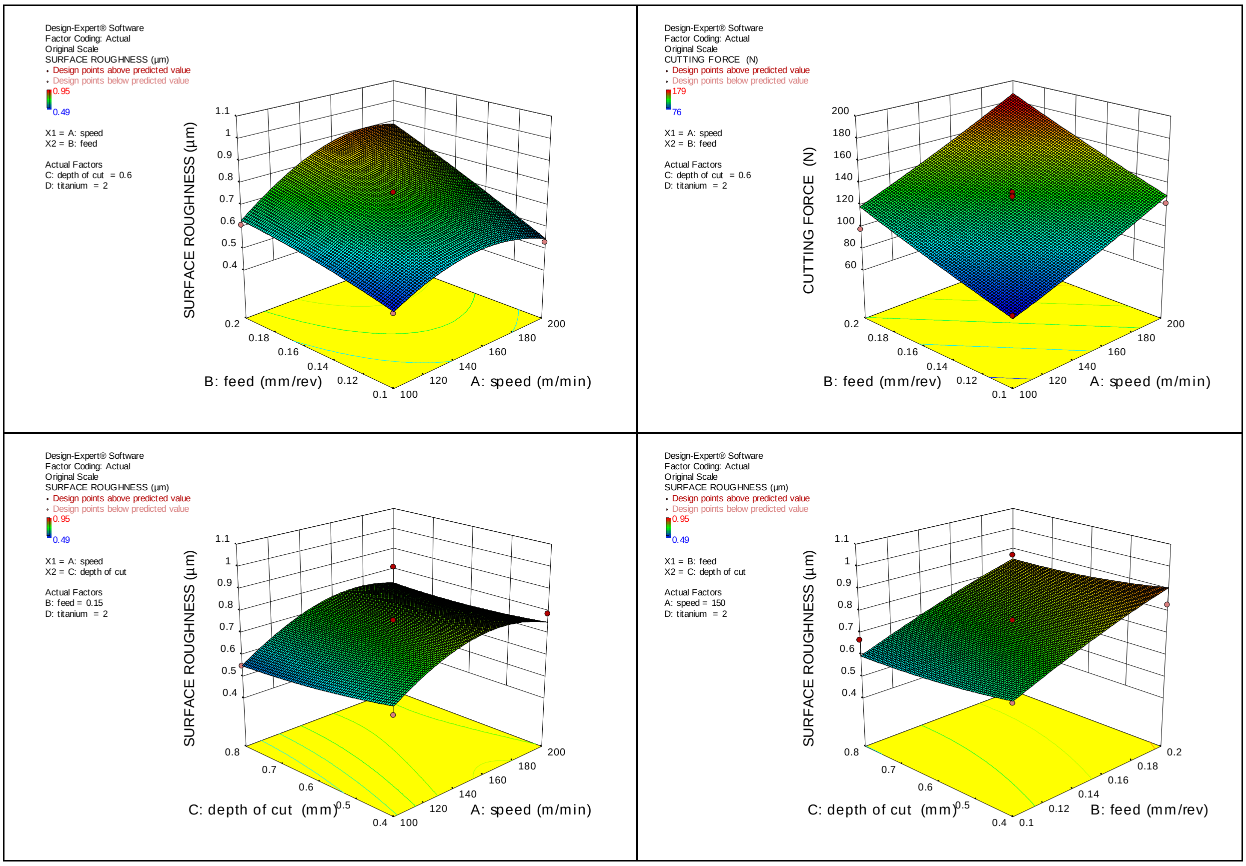

Figure 2: 3D Surface Graphs for Ra & Fc data

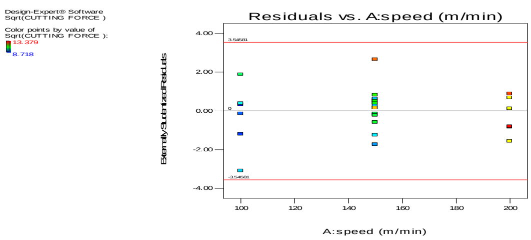

Figure 3: Plot for Residual Vs Speed

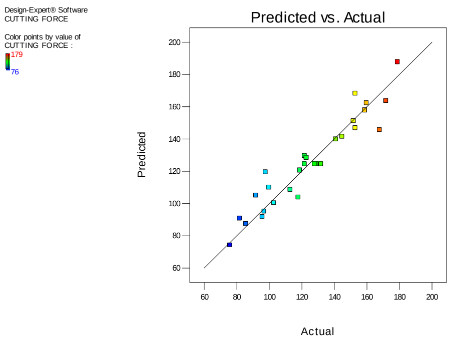

Figure 4: Plot for Predicated Vs Actual

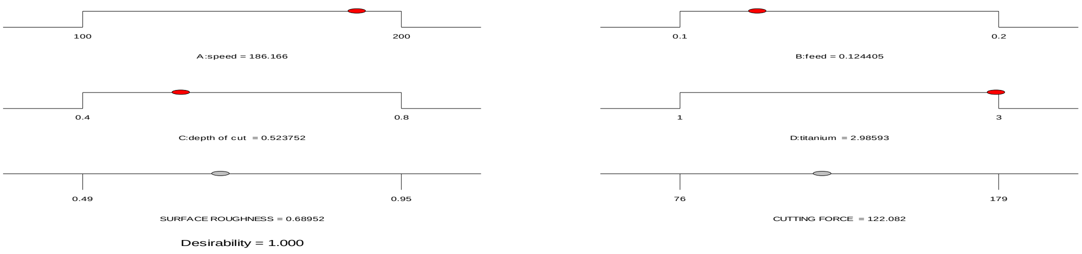

Figure 5: Plot for Desirability

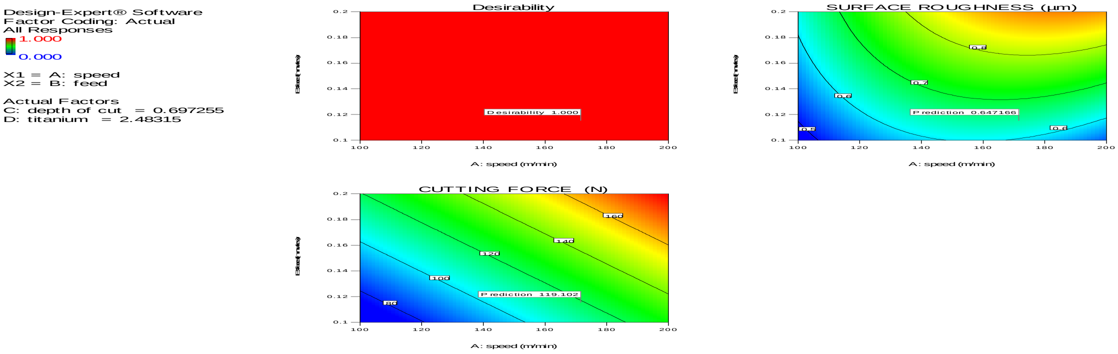

Figure 6: Plot for Predicated Vs Actual

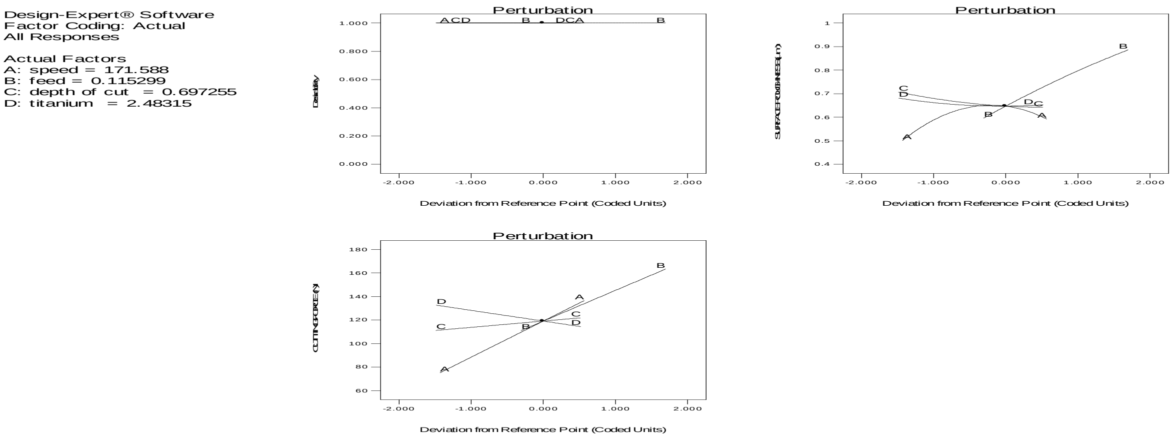

Figure 7: Plot for Perturbation Desirability Ra and Fc

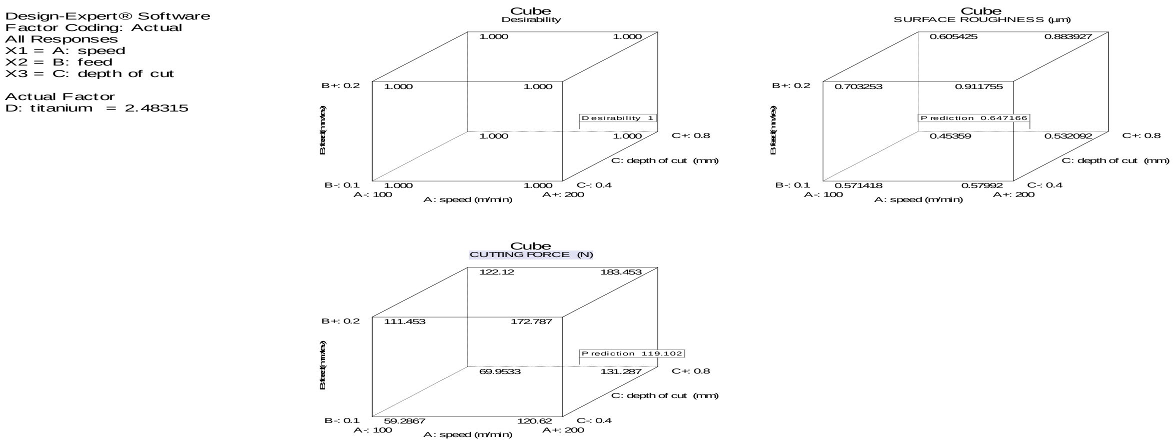

Figure 8: Plot for Predicated Desirability, Ra and Fc

Table 7

Name	Level	Low Level	High Level	Std. Dev.	Coding
Speed(m/min)	171.59	100.00	200.00	0.000	Actual
Feed(mm/rev)	0.12	0.10	0.20	0.000	Actual
depth of cut(mm)	0.70	0.40	0.80	0.000	Actual
Titanium(ti-6al-4v)	2.48	1.00	3.00	0.000	Actual
surface roughness	0.647166	0.49	0.80	0.0636144	Actual
cutting force	119.102	98.23	139.98	9.51857	Actual

CONCLUSIONS

Based on the results of the present experimental investigations on machining different titanium alloys (TI-2, Ti-6Al-4V, and TI-6AL- 4V ELI) alloy, the following conclusions are drawn: high cutting speed, low feed rate, with low depth of cutting is helpful for achieving the good surface roughness. Lower speed, high feed and low depth of cut are for low cutting forces during theturning of titanium alloys, after machining and optimization by using uncoated carbide tools good for machining Ti-6AL-4V Alloy. The cuttingspeeds171.59m/min feed rate 0.12mm/rev have major effects on minimizing surface roughness. The lubrication also plays a vital role in minimizing the surface roughness, the surface roughness is 0.647 µm, cutting force 119.102N. The surface roughness decrease with increased cutting speed, whereas the surface roughness increases with increased feed rate and depth of cut, cutting force increases with increased speed decreases with decrease in the feed and depth of cut. A second-order response surface model for surface roughness has been developed from the data. The predicted and measured values are fairly close, which indicates that the developed model can be effectively used to predict the surface roughness on machining of Ti-6Al4V alloy with 95% confidence intervals. Using such model, one can obtain remarkable savings in time and cost. The result obtained shows that with a proper selection of machining parameters, it is possible to obtain a better performance in turning off Ti-6Al-4V alloy. Uncoated carbide insert was successfully used as a cutting tool material for machining titanium alloys for the better surface finish.

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